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Chapter 1 introduction

Summarized from [Britannica Academic website]

Seismic survey, method of investigating subterranean structure, particularly as related to exploration for petroleum, natural gas, and mineral deposits. The technique is based on determinations of the time interval that elapses between the initiation of a seismic wave at a selected shot point and the arrival of reflected or refracted impulses at one or more seismic detectors .Seismic air guns are commonly used to initiate the seismic waves. This technique has largely replaced the practice of exploding dynamite underground. Electric vibrators or falling weights (thumpers) may also be employed at sites where an underground explosion might cause damage. Upon arrival at the detectors, the amplitude and timing of waves are recorded to give a seismogram (record of ground vibrations) as shown in (Fig.2).

Generally, the density of rocks near the surface of the Earth increases with depth. Here the second layer in the diagram is denser than the first as shown in (Fig.1). Seismic waves initiated at the shot point may reach the receiving point by reflection, refraction, or both. When the shot point is close to the receiving point, reflected waves usually reach the receiving point first. At greater distances, however, the seismic pulse travels faster by the refraction path because its velocity is greater along the top of the lower, denser layer than it is through the upper layer; in this case, the refracted wave arrives first.

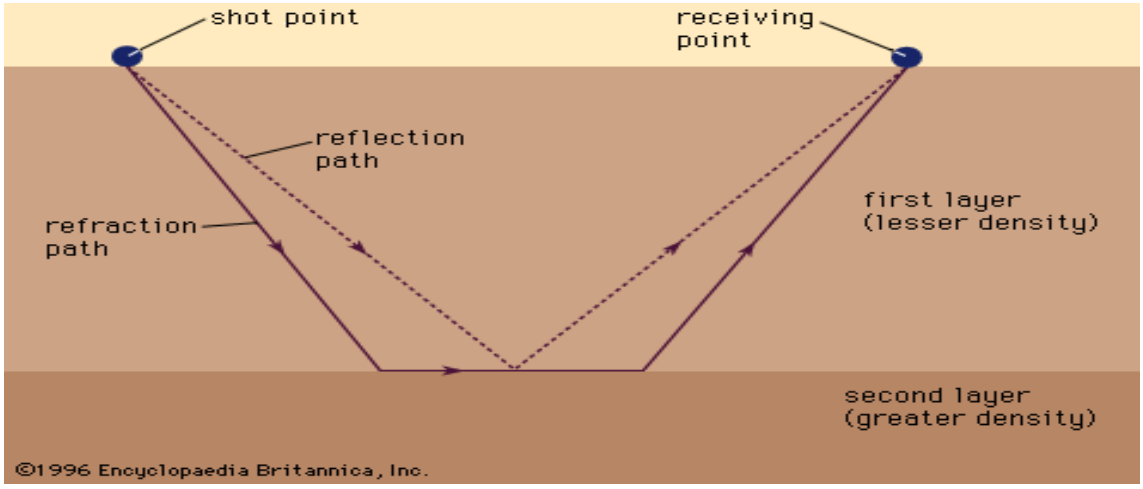

Fig.1 (Seismic survey)

The results of a seismic survey may be presented in the form of a cross-sectional drawing of the subsurface structures , Such drawings are called seismic profiles.

Seismic methods are based on measurements of the time interval between initiation of a seismic (elastic) wave and its arrival at detectors. The seismic wave may be generated by an explosion, a dropped weight, a mechanical vibrator, a bubble of high-pressure air injected into water, or other sources. The seismic wave is detected by a Geophone on land or by a hydrophone in water. An electromagnetic Geophone generates a voltage when a seismic wave produces relative motion of a wire coil in the field of a magnet, whereas a ceramic hydrophone generates a voltage when deformed by passage of a seismic wave. Data are usually recorded on magnetic tape for subsequent processing and display.

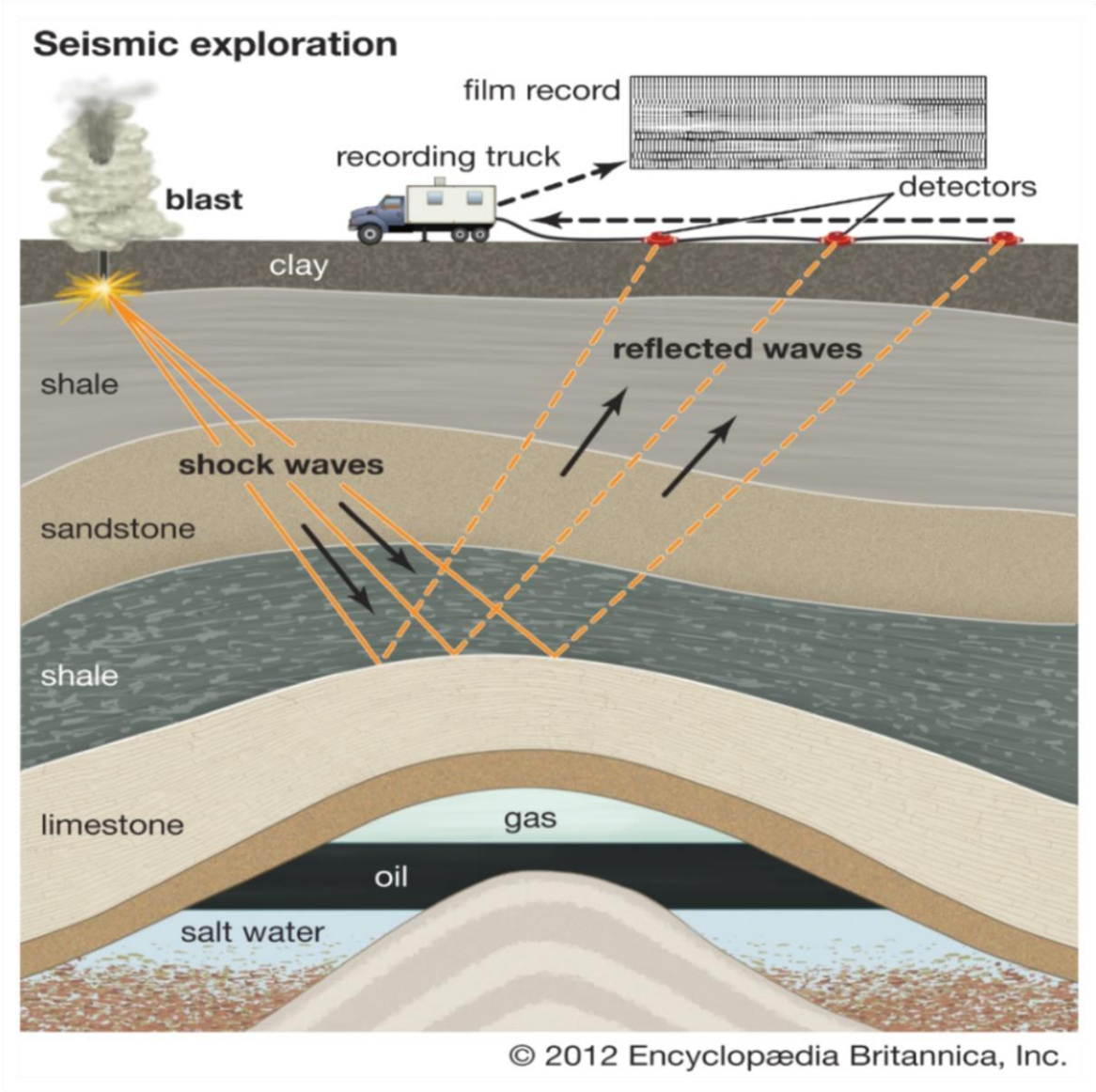

Fig.2 (Basic theory of seismic)

Types of seismic methods

- Refraction method
- Reflection method

Refraction method

Very shallow seismic refraction is extensively used in engineering studies. Sometimes the energy source for shallow-penetration engineering studies involves simply hitting the ground with a sledgehammer. The ease with which a rock can be ripped by a bulldozer relates to the rock's seismic velocity. S-wave velocity measurements are of special interest to engineers because building stability depends on the shear strength of the foundation rock or soil. Seismic waves may be used for various other purposes. They are employed, for example, to detect faults that may disrupt a coal seam or fractures that may allow water penetration into a tunnel .

Reflection method

Most seismic work utilizes reflection techniques. Sources and Geophones are essentially the same as those used in refraction methods. The concept is similar to echo sounding: seismic waves are reflected at interfaces where rock properties change and the round-trip travel time, together with velocity information, gives the distance to the interface. The relief on the interface can be determined by mapping the reflection at many locations. For simple situations the velocity can be determined from the change in arrival time as source–Geophone distance changes.

In practice, the seismic reflection method is much more complicated.The seismic reflection method usually gives better resolution (i.e., makes it possible to see smaller features) than other methods.

Types of seismic waves

- Body waves (P-wave , S-wave)
- Surface waves (Love wave , Rayleigh wave)

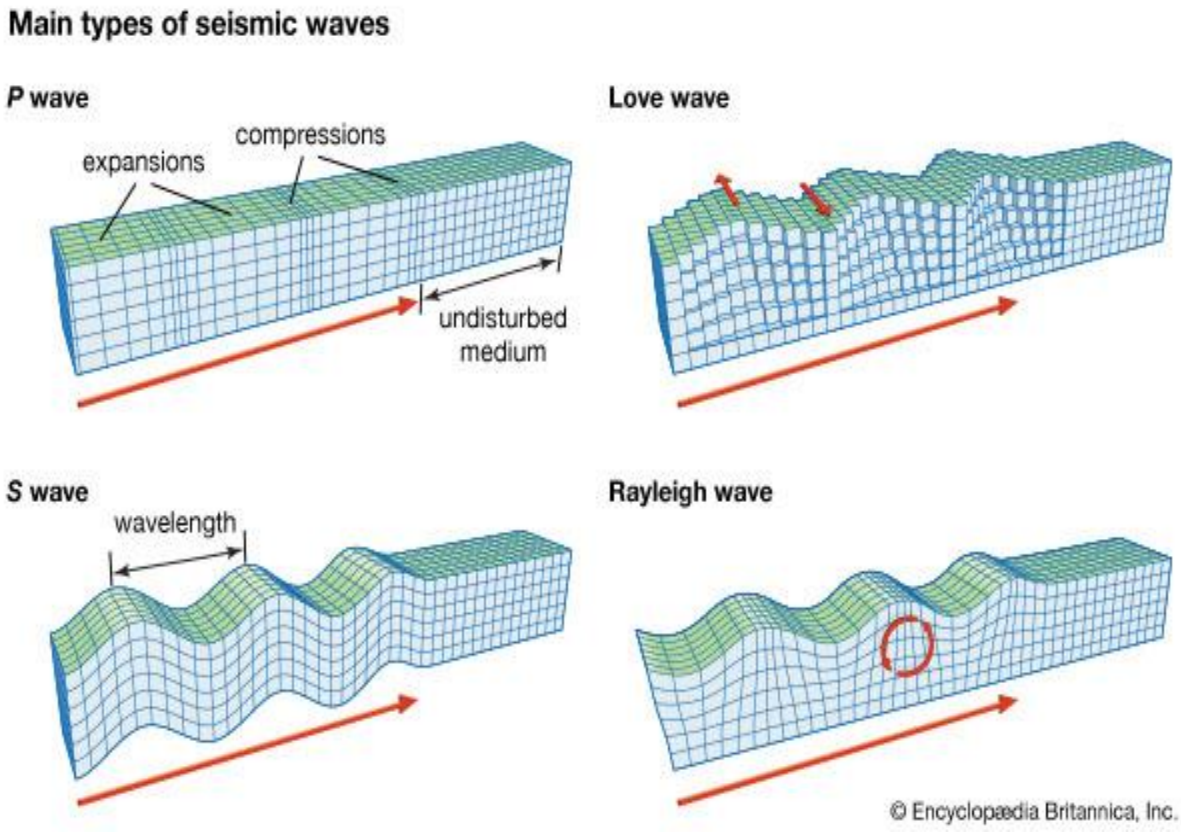

Fig.3 Diagram showing the main types of seismic waves: P (primary), S (secondary), Love, and Rayleigh.

Two types of seismic waves can travel through a body: P waves (primary) and S waves (secondary). **P waves** are compressional waves and travel at the highest velocity; hence, they arrive first. **S waves** are shear waves that travel at a slower rate and are not able to pass through liquids that do not possess shear strength. In addition, there are several types of seismic waves that can travel along surfaces. A major type of surface wave is the **Rayleigh wave**, in which a particle moves in an

elliptical path in the vertical plane from the source. The horizontal component of Rayleigh waves is probably the principal cause of damage from earthquakes. **Love waves** are another type of surface wave; they involve shear motion. Still other varieties of surface waves can be transmitted through low-velocity layers (**channel waves**) or along the surface of a borehole (**tube waves**).

Applications of seismic

- Oil exploration
- Stratigraphic mapping
- Estimation of depth to bedrock
- Estimation of depth to water table
- Landfill investigations
- Geotechnical investigations (environmental-geophysics Website)

Chapter 2 seismic acquisition

Seismic data acquisition is the gathering / recording of seismic data in the field (be it on land or at sea) with the ultimate goal to make a seismic image of the subsurface , see fig.4 . [Drijkoningen , 2003]

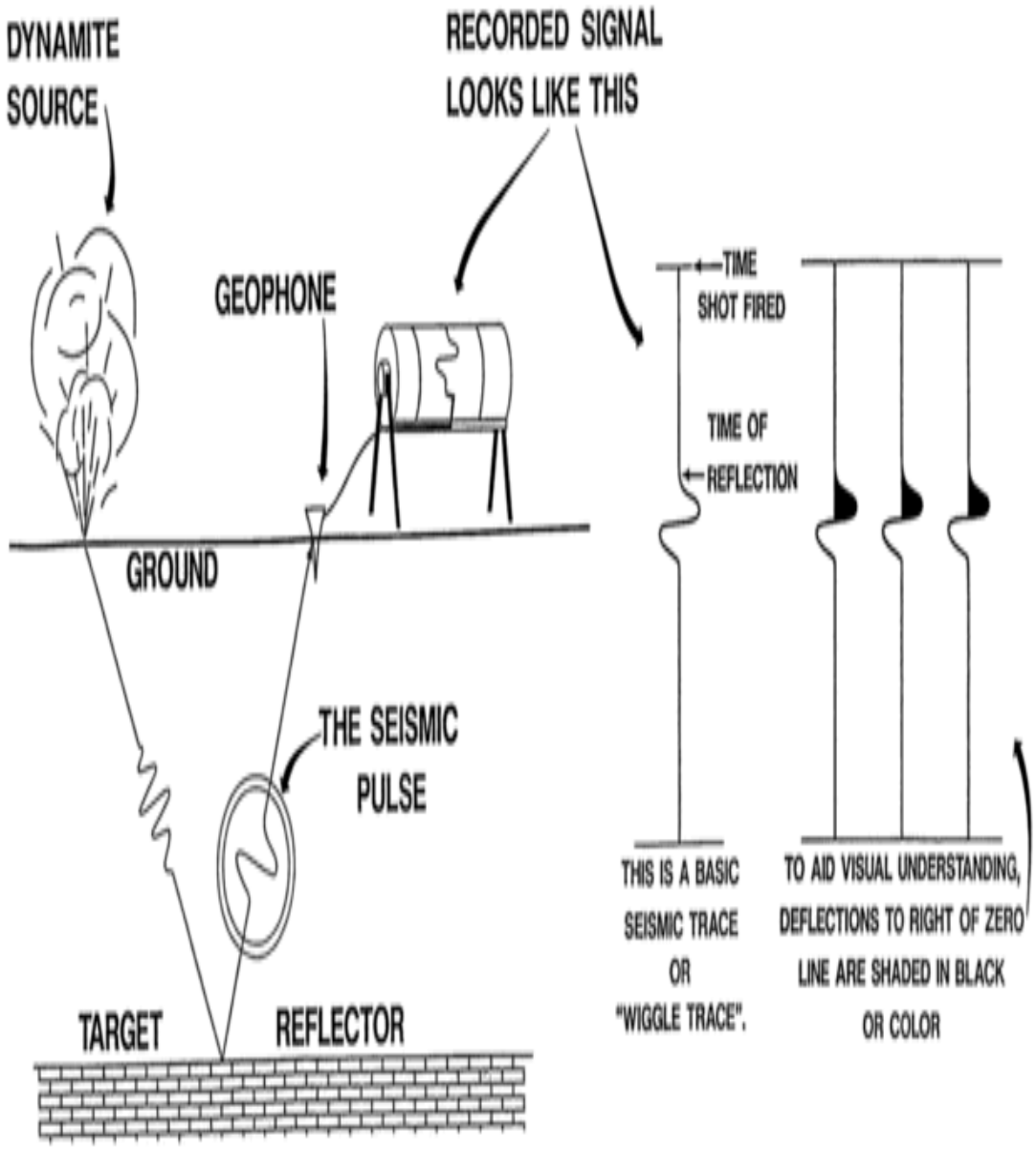
DYNAMITE SOURCE
RECORDED SIGNAL LOOKS LIKE THIS
GEOPHONE
TIME SHOT FIRED
TIME OF REFLECTION
GROUND
THE SEISMIC PULSE
TARGET
REFLECTOR
THIS IS A BASIC SEISMIC TRACE OR "WIGGLE TRACE".
TO AID VISUAL UNDERSTANDING, DEFLECTIONS TO RIGHT OF ZERO LINE ARE SHADED IN BLACK OR COLOR

Fig.4(seismic acquisition) [walter.kessinger website]

Components of seismic acquisition

- Seismic sources
- Seismic receivers
- Seismic cables
- Seismic recorders

Seismic sources

- DYNAMITE SOURCES

The predominant seismic source used in land prospecting is dynamite exploded in boreholes. Dynamite is a highly concentrated source of energy; it produces an intense impulsive signature and is simple to use. It is also expensive, and the requirement of drilled holes adds significantly to the overall exploration costs. It is also destructive and cannot be used near dwellings, water wells, and so forth. [Sengbush, 1983]

- VIBROSEIS SOURCES

Vibroseis (trademark of Continental Oil Company) is the surface source that threatens to displace dynamite in seismic prospecting on land as shown in (Fig.5). Based on an entirely new concept for seismic sources, it had its origin in chirp radar developed by Bell Laboratories after World War II (Klauder et aI , 1960). Until that development, radar had always increased its range by transmitting more intense impulses. Chirp radar increases energy by transmitting along, oscillatory signature whose instantaneous frequency changes linearly with time. Each received echo is compressed to a pulse by correlating the received signal with the input signature. Conoco applied the chirp principle to seismic prospecting (Crawford et al , 1960)

Fig.5 [vibroseis sources] [nwmo.ca website]

Seismic receivers

It is convenient to distinguish between motion sensors, which measure the projection of a motion (displacement, velocity, or acceleration) along one or several axes, and pressure sensors, which measure pressure. [Meunier, 2011]

- Electromagnetic geophone

Its size and mass have decreased from 15 cm and 6 kg, respectively to 3.2 cm and 74 g, respectively . The size of the geophone has remained unchanged during that time. A coil is attached to a moving mass suspended by a spring to a structure coupled to the ground as shown in (Fig.6). The structure includes a permanent magnet that generates a magnetic field in the region of the coil. Relative motion of the magnetic field and coil generates current in the coil and voltage across the output terminals, proportional to the velocity of the ground motion. [Meunier, 2011]

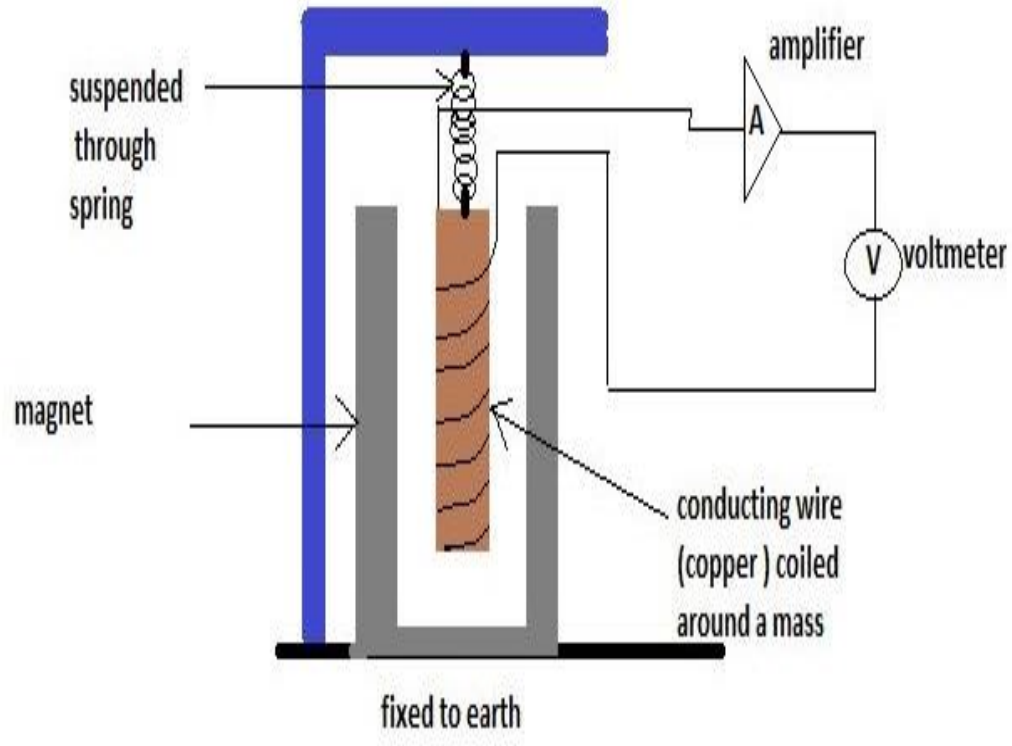

Fig.6 [simple model of geophone] [1.bp.blogspot]

Seismic cables

Today, virtually all seismic cables used for 3D acquisition are digital. That means preamplification and analog-to digital conversion operations have migrated from the instrument truck to the line. To reduce the number of connections (which are the cause of a large proportion of problems), some systems have inserted the electronic components that perform those operations into the cable itself. The technological challenge was to enable the electronic components to work in the field (in temperatures ranging from −35°C to 50°C and in dry air and under a few decimeters of water) with the same performance as in an air-conditioned cabin. That was the

necessary condition for the deployment and subsequent recording of very large numbers of receivers as shown in (Fig.7).[Meunier, 2011]

Fig.7 [Seismic work] [geos.ed.ac.uk website]

Seismic recorders

Modern seismic recorders face several challenges. Methods to address those challenges are either specific to one manufacturer or are used by all manufacturers.

The first challenge is to increase the system capacity to record larger numbers of seismic channels (a seismic channel is the electronic equipment necessary to record signal sent by one receiver).

The second challenge, sensitivity, is not new. However, the use of single-sensor acquisition has resulted in a lower receiver sensitivity that might have to be compensated for by a higher preamplifier gain.

The third challenge, dynamic range, is not new either, but single-sensor or shorter arrays do not provide the same attenuation of surface waves as receiver arrays provided. Nonseismic noise is **the fourth challenge**. [Meunier, 2011]

Signal and noise

Signal

One definition of signal (Merriam Webster's Collegiate Dictionary, eleventh edition) is "a detectable physical quantity or impulse (as a voltage, current, or magnetic field strength) by which messages or information can be transmitted." The concept of a transmitted message applies well in our field of activity. In reflection seismology, signal could be defined as ground motion (or pressure under the sea surface) caused by the arrival of seismic waves after they have been reflected by the geologic layers to be imaged. There are three components in that definition: (1) a source, which ideally should be known and often is not; (2) a propagation, which bears the information needed to make images; and (3) a measure that uses receivers, amplifiers, and recorders to transform ground motion or pressure near the sea surface into seismograms.

Noise

Many definitions can be found in various domains of application. In physics, noise is a disturbance, especially a random and persistent disturbance that obscures or reduces the clarity of signal. In computer science, noise is irrelevant or meaningless data. Most definitions indicate something other than the desired signal. Noise is relative to the observer.

Sorting of seismic data

Summarized from [Drijkoningen, Verschuur, 2003]

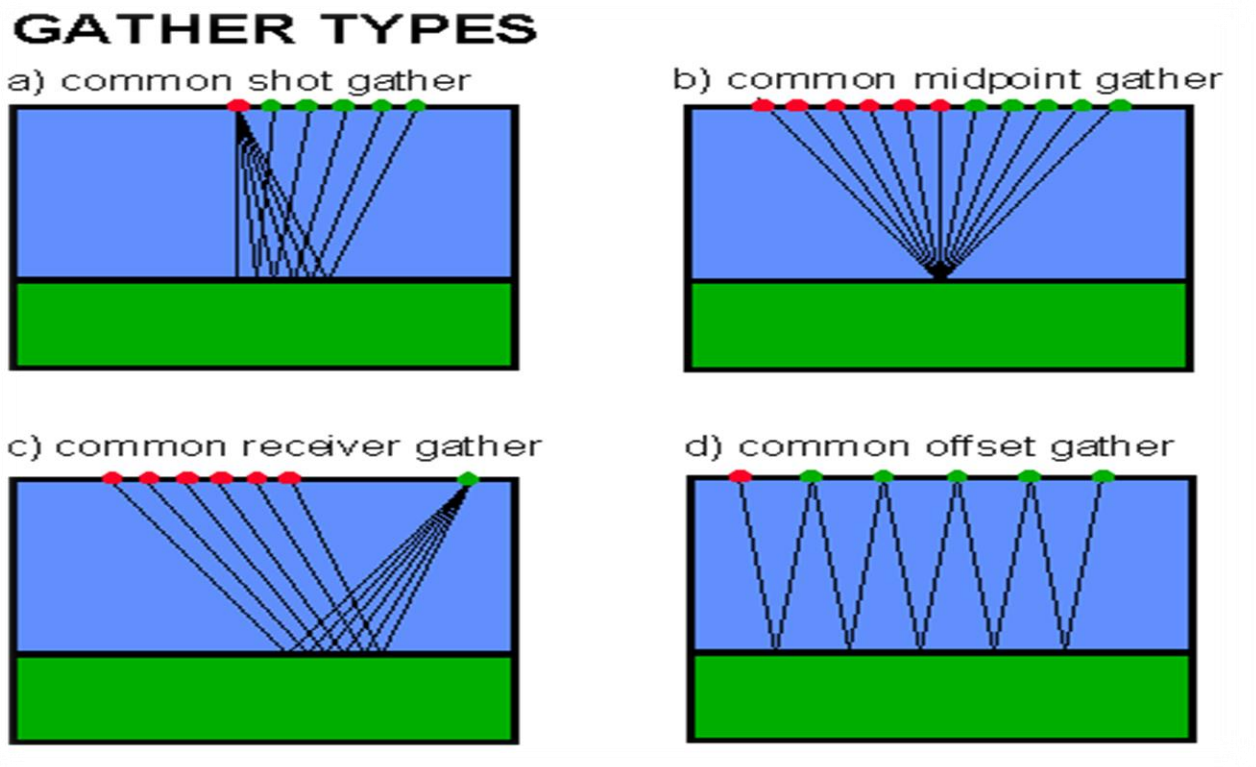

Fig.8 [gather types] [xsgeo website]

Common shot and common receiver gathers

When data is shot in the field, we record the shots sequentially. By a (shot) record we mean all the recordings from the sensors for a single shot experiment. Normally, the measurement for one source at one receiver location is called a trace, which is a time series of reactions. It is obvious that for each shot we will order these recordings (traces) by increasing (or decreasing) offset. The offset is defined as the distance from source to receiver. It can be guessed that if we talk about shot ordered data, we could also have receiver ordered data.

Common midpoint gathers

A gather for one mid-point position with the traces for increasing (or decreasing) offsets is called a common midpoint gather (or panel).

Common offset gathers

As can be expected, we can also form a common-offset gather, a gather in which we collect all those source receiver pairs that have a certain offset in common. Usually, we shoot with fixed distances between source and receivers, and so we will have as many traces in our common-offset gather as there are shots, thus often quite a large amount as shown in (Fig.8).

Chapter 3 seismic processing

Static correction

Before carrying out the NMO correction it is usually necessary to perform a static correction, which amounts to moving the entire seismic trace up or down in time. [gpg website]

There are two main reasons for applying static corrections.

1. Put shots and receivers on a flat datum plane.
2. Correct for near surface velocity anomalies beneath the source or receiver. as shown in (Fig.9)

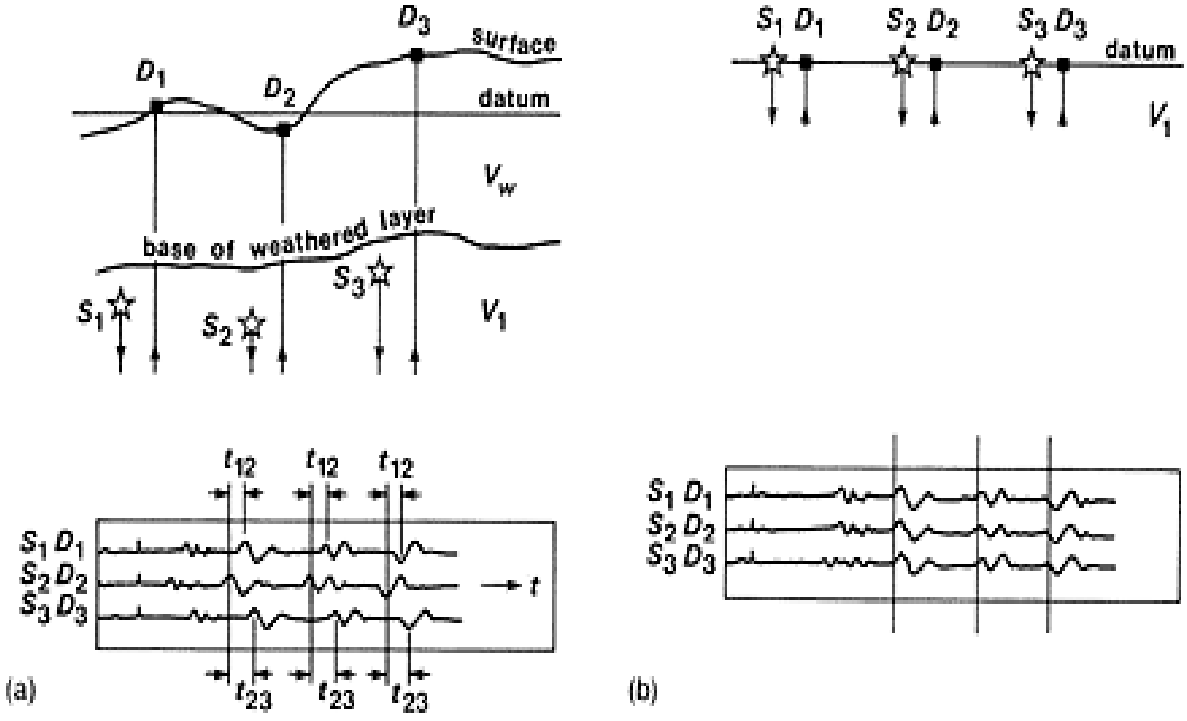

Fig.9 [static correction] [gpg.geosci.xyz website]

Elevation static

Common midpoint shot receiver pairs acquire data on an irregular interface. Time differences are caused because of extra travel time associated with elevation of source and receiver. As a result reflections observed on the CMP gather will not have a hyperbolic form and they will not be amenable to normal CMP processing .[gpg website]

The correction procedure involves establishing a datum on which to locate source and receiver, and then adding or subtracting the incremental time. [gpg website]

Near-surface velocity anomalies

Similar bulk shifts in time will occur if there is anomalous velocity beneath a source or receiver or if the thickness of the weathering layer changes substantially. [gpg website]

CDP technique

Experience in the processing of CDP data is essential to avoid potential pitfalls such as excessive deterioration of the high frequencies during the stacking procedure and incorrect identification of coherent arrivals . The great power of CDP techniques, however, is that the signal-to-noise ratio of the data can be improved to provide subsurface information that was not visible on an optimum offset section as shown in (Fig.10). [ku.edu web site]

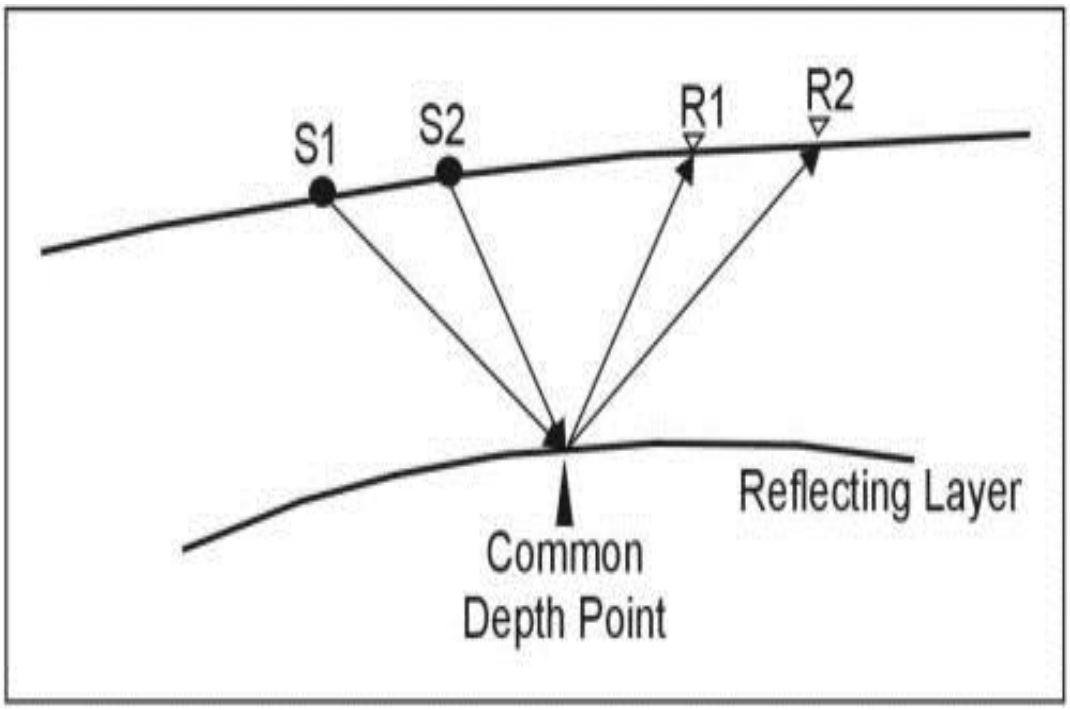

Fig.10 (Common depth point) [epa.gov website]

Gain recovery

The correction for the loss in amplitude of a signal as it travels through the earth and spreads its energy over a larger surface area. [AAPG Wiki]

Deconvolution

A step in seismic signal processing to recover high frequencies, attenuate multiples, equalize amplitudes, produce a zero-phase wavelet or for other purposes that generally affect the wave shape. Deconvolution as shown in (Fig.11), or inverse filtering, can improve seismic data that were adversely affected by filtering, or convolution that occurs naturally as seismic energy is filtered by the Earth. [Oilfield Glossary website]

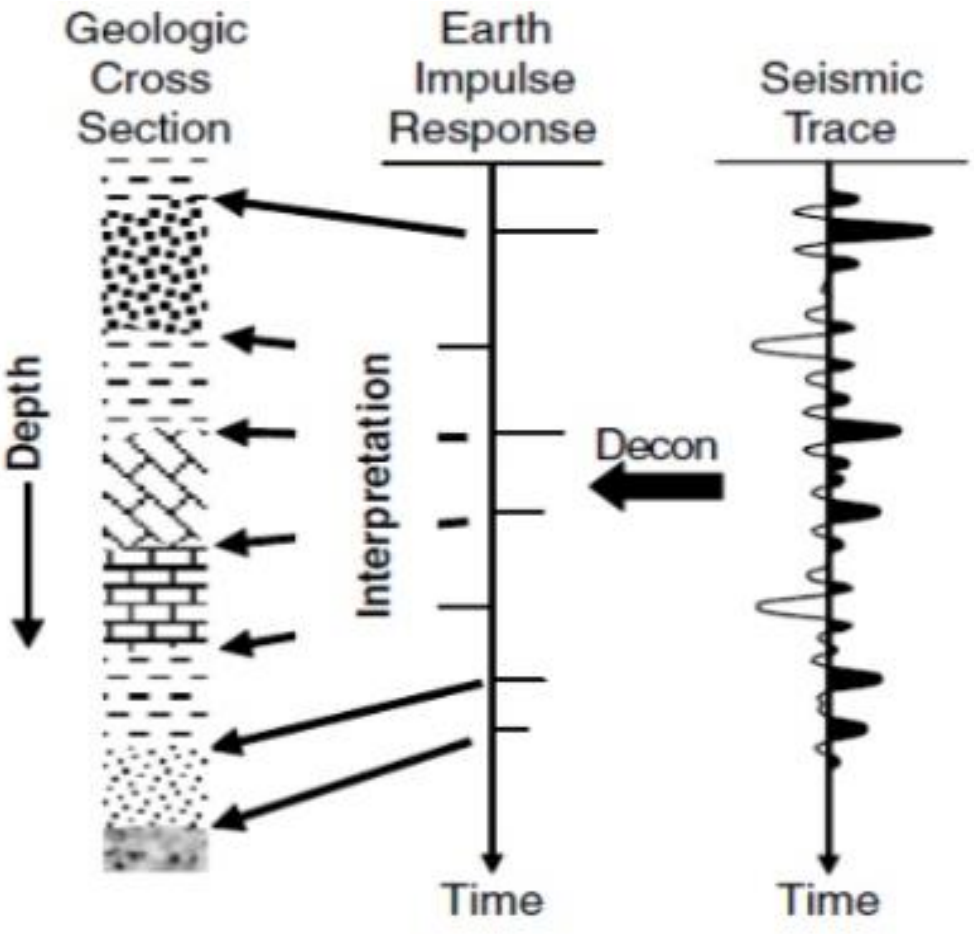

Fig.11 [deconvolution] [slideshare website]

Normal-moveout (NMO) correction

The NMO-Correction depends on the offset and the velocity. In contrast to the static correction, the correction along the trace can differ. The NMO-correction is also called a dynamic correction. [Bairdpetro web site]

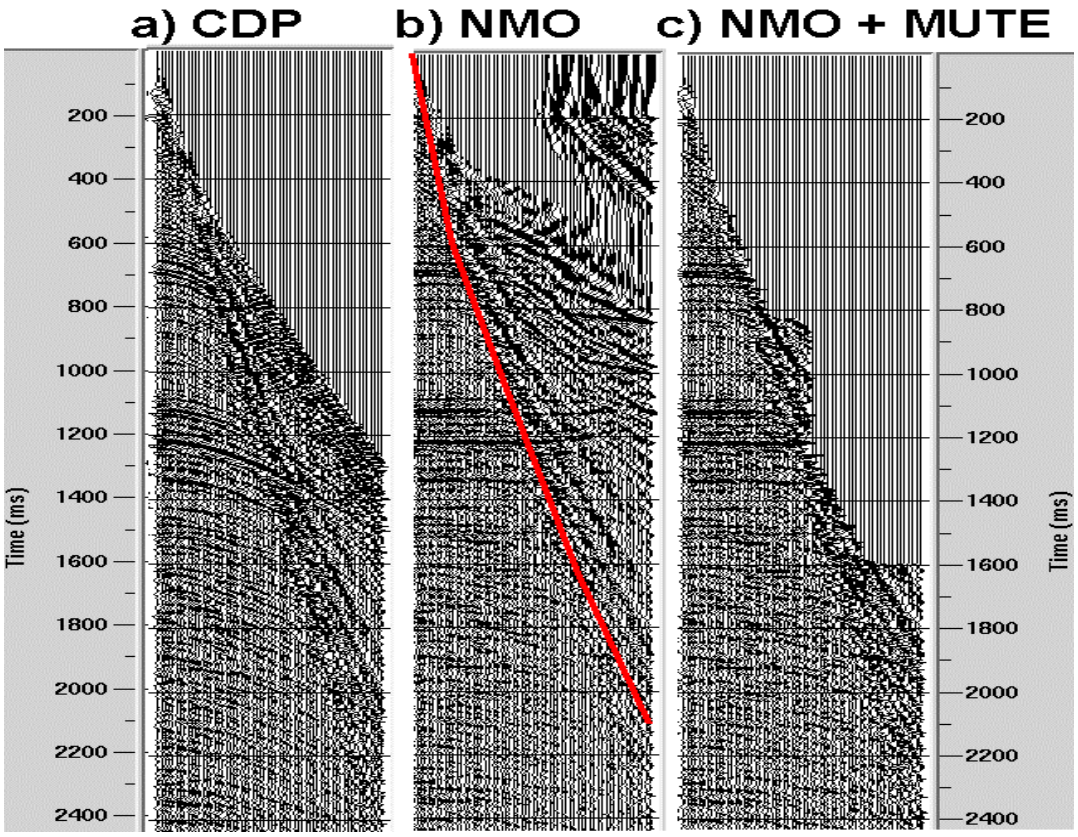

Fig .12 [NMO correction] [xsgeo website]

Dip moveout (DMO) correction

NMO corrections are made under the assumption of horizontal planar reflectors. If the reflector has appreciable dip, then the actual movement will be slightly different. The DMO correction is a method for estimating the effect of dip on moveout and removing it from the records as well [AAPG Wiki]

Stacking

A characteristic of seismic data as obtained for the exploration for oil and gas, is that they generally show a poor signal-to-noise ratio as shown in (Fig.13), not only due to coherent events such as surface waves, but also due to uncorrelated noise. Often, only the strong reflectors show up in raw seismic data. An important goal in seismic processing is to increase the signal-to-noise ratio, and the most important

steps towards this goal, is CMP sorting and stacking. With stacking we add the NMO-corrected traces in a CMP gather to give one output trace. A better nomenclature is perhaps horizontal stacking because we stack in the horizontal direction. This is in contrast to vertical stacking, which is recording the data at the same place from the same shot position several times and adding (i.e.averaging) these results.[AAPG Wiki]

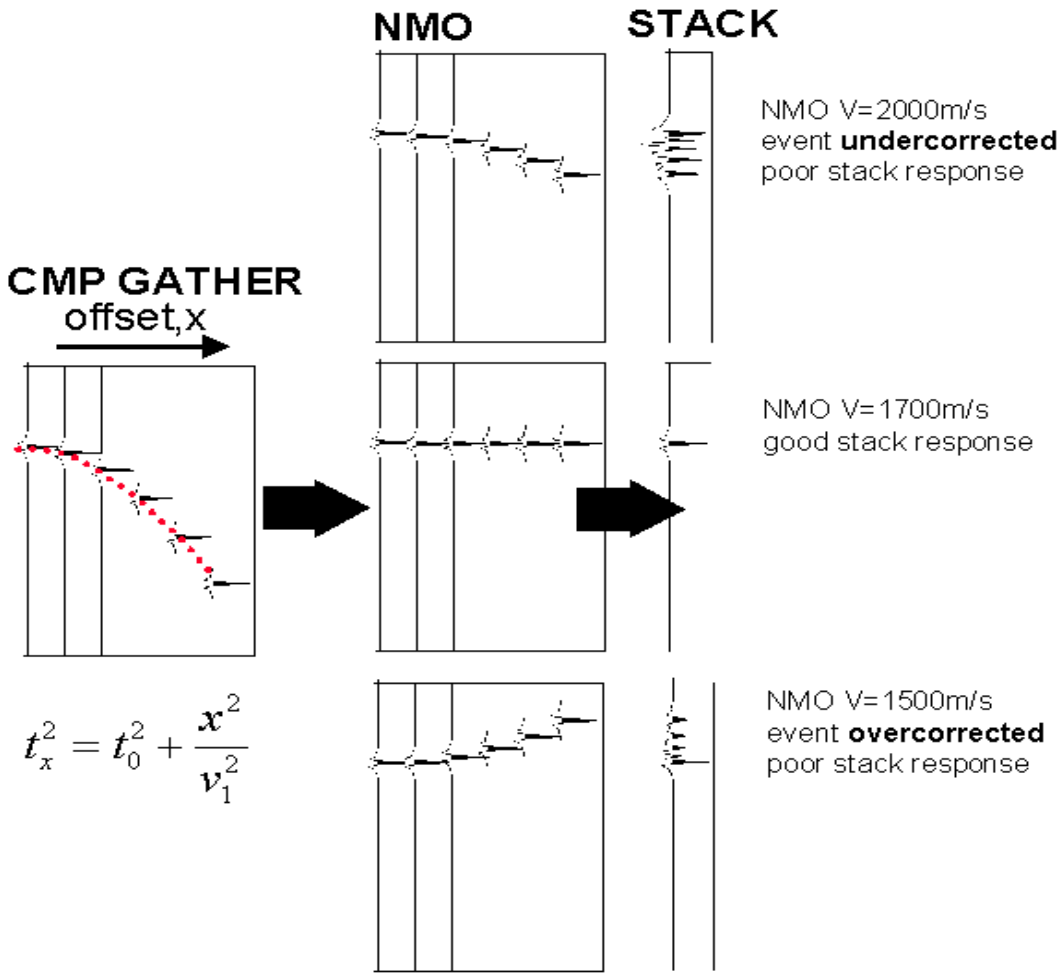

Fig.13 [stacking] [xsgeo website]

Migration

Seismic migration is the process by which seismic events are geometrically re-located in either space or time to the location the event occurred in the subsurface rather than the location that it was recorded at the surface, thereby creating a more accurate image of the subsurface as shown in (fig.14). This process is necessary to overcome the limitations of geophysical methods imposed by areas of complex geology, such as: faults, salt bodies, folding, etc. [AAPG Wiki]

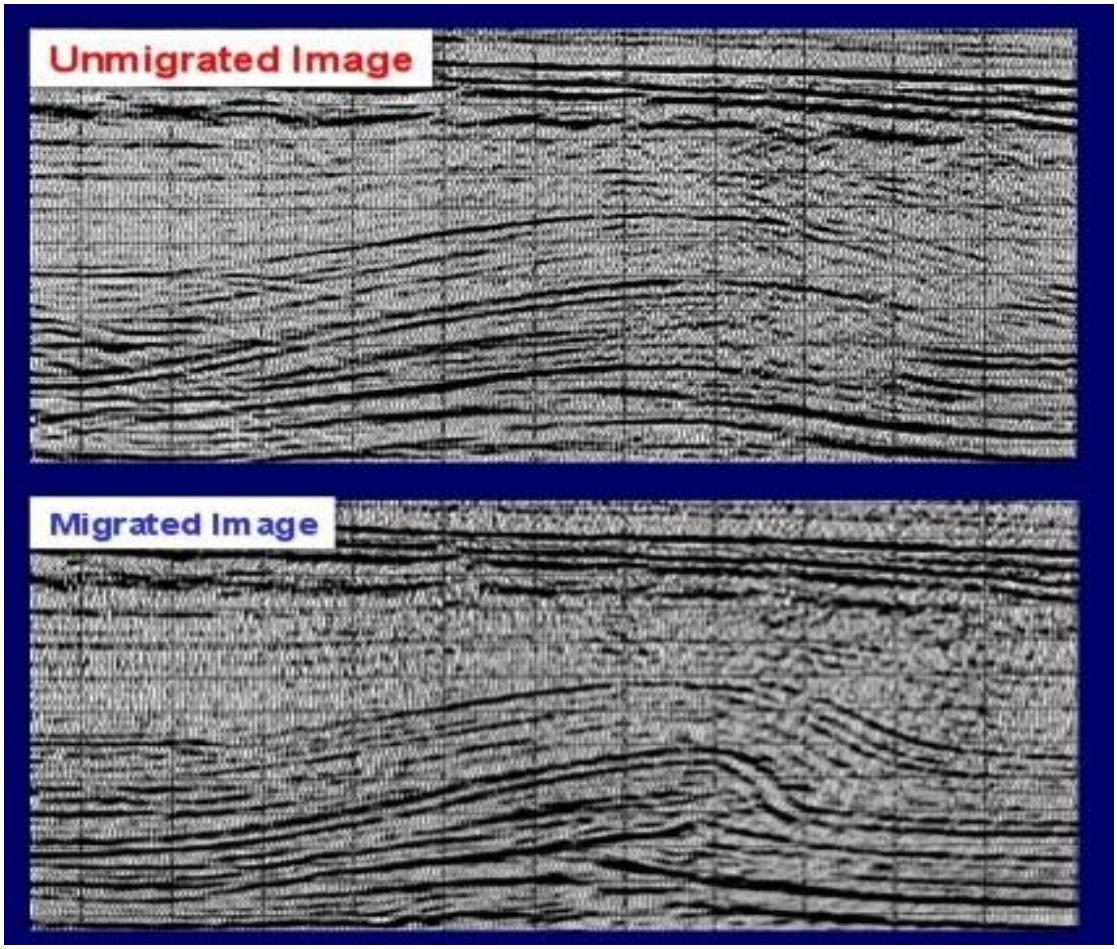

Fig.14 [migration] [AAPG web site]

Types of migration

Time migration

Time Migration is applied to seismic data in time coordinates .This type of migration makes the assumption of only mild lateral velocity variations and this breaks down in the presence of most interesting and complex subsurface structures, particularly salt. [AAPG Wiki]

Depth migration

Depth Migration is applied to seismic data in depth (regular Cartesian) coordinates, which must be calculated from seismic data in time coordinates. The significant advantage to this migration method is that it can be successfully used in areas with lateral velocity variations, which tend to be the areas that are most interesting to petroleum geologists. [AAPG Wiki]

Chapter 4 seismic interpretation

Simply defined, seismic interpretation is the science (and art) of inferring the geology at some depth from the processed seismic record. While modern multichannel data have increased the quantity and quality of interpretable data, proper interpretation still requires that the interpreter draw upon his or her geological understanding to pick the most likely interpretation from the many "valid" interpretations that the data allow. [AAPG Wiki web site]

The seismic record contains two basic elements for the interpreter to study. The first is the time of arrival of any reflection (or refraction) from a geological surface. The actual depth to this surface is a function of the thickness and velocity of overlying rock layers. The second is the shape of the reflection, which includes how strong the signal is, what frequencies it contains, and how the frequencies are distributed over the pulse. This information can often be used to support conclusions about the lithology and fluid content of the seismic reflector being evaluated.

The interpretation process can be subdivided into three interrelated categories: structural, stratigraphic, and lithologic. Structural seismic interpretation is directed toward the creation of structural maps of the subsurface from the observed three-dimensional configuration of arrival times. Seismic sequence stratigraphic interpretation relates the pattern of reflections observed to a model of cyclic episodes of deposition. The aim is to develop a chronostratigraphic framework of cyclic, genetically related strata. Lithologie interpretation is aimed at determining changes in pore fluid, porosity, fracture intensity, lithology, and so on from seismic data. Direct hydrocarbon indicators (DHI, HCIs, bright spots, or dim-outs) are elements employed in this lithologic interpretation process.

a basic three-step methodology, which, when followed, provides for a more complete and accurate geological interpretation from seismic data.

Step one: interpretation plan

What are my objectives?

An interpreter should clearly understand what conclusions are required from the data. Because so much information is available on the seismic, it is important to focus maximum attention on extracting the data pertinent to completing the objective task. Does the objective require evaluating the entire dataset from first sample to last, one stratigraphic sequence, or just one specific amplitude anomaly? This dictates what combination of the three basic interpretation types should be used, when the interpretation should be completed, and what supporting databases are required.

What are the regional tectonic, structural, and depositional trends?

It is important for the interpreter to have a basic understanding of what tectonic influences and depositional systems occur within the area of the seismic survey to be investigated. Although this preconceived earth model may be vague and incomplete, particularly in frontier basins, it provides interpreters with insight and constraints as to what types of structures, faulting, and stratigraphic geometries may exist. The interpretation of fault styles, structural geometries, and facies patterns must be consistent with regional tectonic forces and basin infilling.

What seismic patterns should i be looking for?

Perhaps the most common interpretational pitfall, and certainly one of the most dangerous, is the mapping of events, amplitude, or AVO changes without qualification as to what geological analog they represent. To prevent this mistake, it is critical that all types of available geological data be gathered and merged with the seismic data. Key to this merging are well-constructed synthetic seismograms,

vertical seismic profiling (VSP) data, and/or seismic models. This verifies the seismic signature of the target, the location of the mapping horizon, and the adequacy of the time-depth functions. Varying the synthetic seismogram or model parameters allows for the prediction of seismic responses for various lithologics and fluid types.

Step two: building and merging datasets

After developing an interpretation plan, the next step is to begin assembling the complete dataset. An inventory of available seismic data of all vintages is made, including p wave seismic, shear wave seismic, well data, velocity surveys, and VSP. The data are scanned for quality and suitability. At this point, a determination can be made whether the available data can reasonably support the goals of the project.

Available well, core, test, paleontology, and outcrop data are gathered and organized for integration with the seismic data. Where available, gravity and magnetics data should be tied to the seismic data to identify the location of basement, salt bodies, igneous intrusives, and shale masses. Another type of data that sheds light on the geological conditions of a specific reservoir is pressure and production history data. These data can provide information on the presence and proximity of faulting and the size of fault blocks.

If digital data are available, a decision must be made whether to use a workstation or proceed with a "paper interpretation." Generally, a workstation offers the interpreter a valuable edge achieving a "correct" interpretation where detail is important. For much regional work, paper is often still the most used medium due to the display limitations of the workstation screen. Seismic interpretations on paper, however, can always be digitized later for computer mapping or incorporation into a workstation project.

Step three: interpretation

The process of interpreting seismic data eventually comes down to putting pencil to paper or cursor to screen. After building an exploration analog by integrating the available geological data, it is advisable to scan the dataset to observe the basin setting, major structural components, and major stratigraphic components, such as reefs, shelf breaks, and major sequence boundaries. While scanning, major faults can be picked as a guide to establishing the dominant structural style.

After scanning, detailed mapping begins by working outward from a point where geological information exists, preferably a well location with a synthetic seismogram. The horizons selected for mapping and observed fault cuts are correlated from the well to the seismic. The interpreter then begins to pick these same events away from the well on the seismic, being careful to tie at all other well locations.

Tying all lines in both 2-D and 3-D data sets is the only way to reliably construct a three-dimensional model of the subsurface using two-dimensional images. After all lines are picked and tied, the results of the interpretation are then summarized and presented as maps. Basically, any observation that can be made using seismic data can be posted on a base map and mapped. Maps that are routinely made include

- ✓ Time structure maps with faults
- ✓ Depth structure maps
- ✓ Seismic facies maps for reservoir, source, or seal analysis
- ✓ Seismic velocity maps for lithology determination or depth conversion

The only limitations in constructing these maps are the imagination and skill of the interpreter.

The overall aim of seismic interpretation is to aid in constructing the most accurate earth model or reservoir description possible. This can best be accomplished when

the seismic data are merged with petrophysical, geological, and engineering databases.

Case Study

Deducing the subsurface geological conditions and structural framework of the NE Gulf Of Suez area, using 2-d and 3-d seismic data

Summarized from [Zahra & Nakhla 2015]

An interpretation of the seismic data of Ras Budran and Abu Zenima oil fields, northern central Gulf of Suez, is carried out to evaluate its subsurface tectonic setting. The structural configuration, as well as the tectonic features of the concerned area is criticized through the study of 2D and 3D seismic data interpretation with the available geological data.

Ras Budran field is located in the northern of Abu Rudeis offshore area, approximately 4 km from the eastern coast of the Gulf of Suez at a water depth of about forty-two meters.Abu Zenima field is located between the oil fields of Rudeis–Sidri, October and Ras Budran , as shown in (Fig.15).

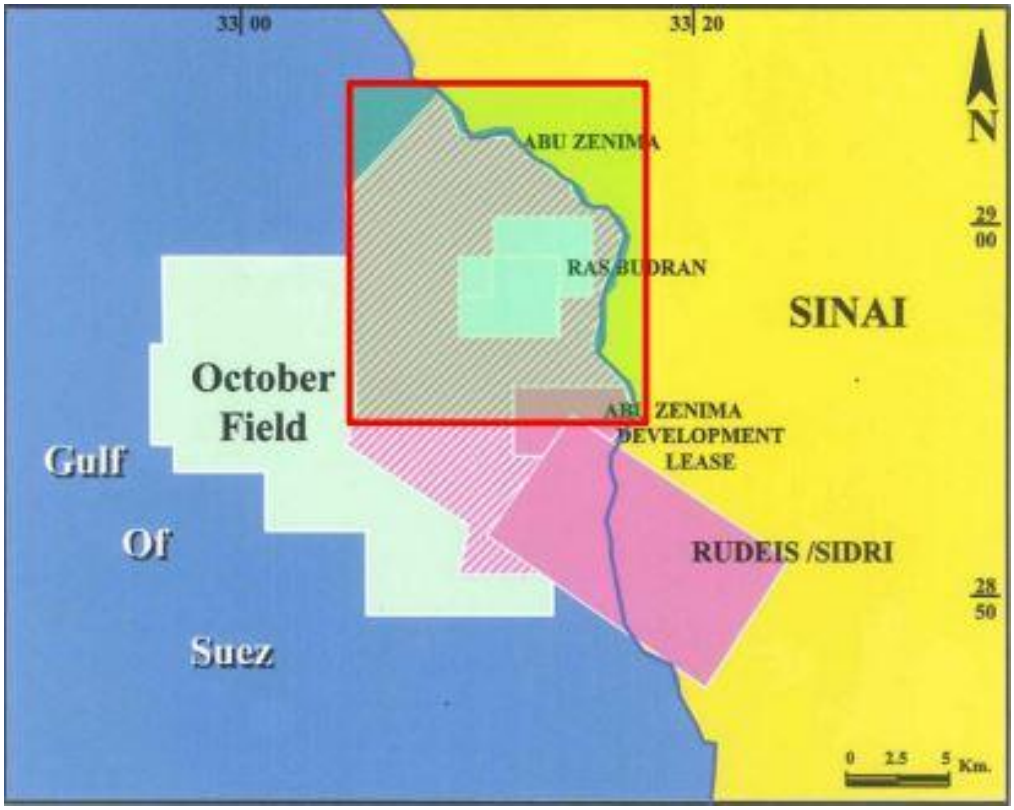

Fig.15 Location map of the study area.

Geological setting

A sedimentary sequence as shown in (Fig.16),ranging in age from Paleozoic to Recent with non depositional and erosional hiatuses was penetrated in the area of consideration the tectonic setting and depositional history of the central part of the Gulf of Suez can be classified into three major tectonic and depositional phases namely : Pre-Rift, Syn-Rift and Post-Rift tectonic phases that controlled the deposition and the sedimentary sequences in the Gulf of Suez.

The Pre-Rift phase: comprises the sedimentary units overlying the basement to Eocene. It is made up of initially clastic sediments associated with continental and fluvio-marine environments, which form the Nubia Sandstone sequence of Cambrian–Lower Cretaceous. This was followed by the marine sediments of Upper Cretaceous till the Late Middle Eocene. Basaltic igneous activities affected the area

occurred during the Oligocene–Early Miocene are related to the initial faulting of the Suez rift. Dykes generally trend NW, sub-parallel to the rift trend.

Syn-Rift phase: The rifting that formed the Gulf of Suez graben occurred during the Oligocene and Normal faulting occurred in multiple stages.The basal Miocene marine sediments (Nukhul Formation) lie on the Middle Eocene (Thebes Formation) or younger rocks. By the Early Miocene, the rift system was well established and had subsided enough to be inundated by the sea. Shaley-marly sediments of Early Rudeis age were deposited.

The most intense phase of tectonics within the Gulf was an intra-Rudeis (mid Clysmic) event. As a result of this phase, the rift shoulders were elevated and the rift was confined mainly to the central trough (Garfunkel and Bartov, 1977). The structure of the rift is dominated by major NW–SE trend (Clysmic system) and subsidiary NE–SW trending normal faults (Aqaba system). The stretching of the rift is devoid of any compressional structures (Gilboa and Cohen, 1979).

Post-Rift phase: It is a period of emergence and tectonic quiescence, which began in the Pliocene and many faults remained inactive. This includes the Pliocene and Pleistocene sediments that accumulated in the rift basin after the gulf activity became quiescence. These are a package of coarse clastics of sandstone and conglomeratic intercalations overlying the top Miocene unconformity surface. Most of the tectonic activity was confined in the central part of the rift and was stronger to the south.

Understanding the growth, linkage and death of fault segments and reconstruction of the early rift structure has important implications for subtle trap and reservoir distribution in rift basins (Jackson et al., 2002).

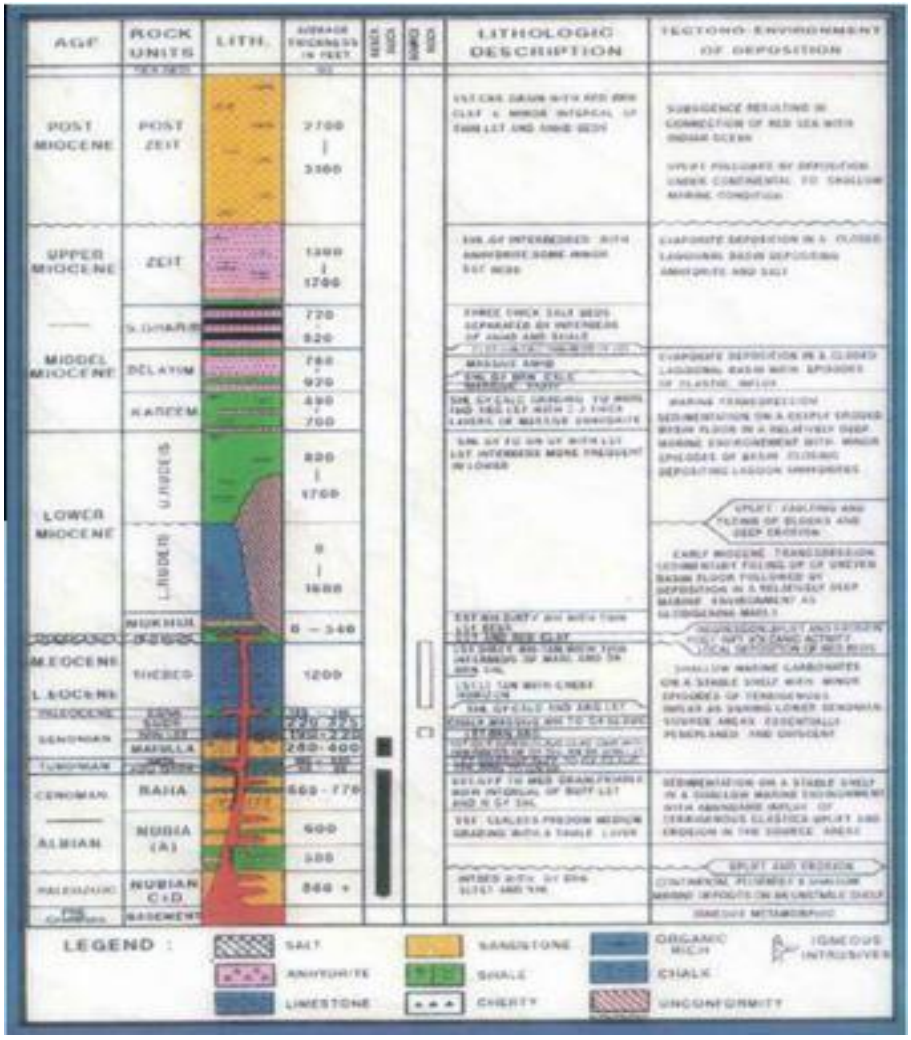

Fig.16 Generalized stratigraphic column of Ras Budran–Abu Zeneima fields.

Seismic data of study area

The geophysical problems faced in the Ras Budran area are summarized as follows:

1. The small acoustic impedance contrast at all levels below top Rudeis.
2. The absorption of most seismic energy at the shallow evaporitic sequence.
3. The difficulties arisen from the effective multiple attenuation, due to the thick sequences of interbedded shales, sands, salts and anhydrite in the Miocene section.

Interpretation of 2D seismic data

A number of seismic lines were selected and interpreted with the help of well velocity surveys and time-depth trace conversion to construct the structural maps characterizing the different levels of the concerned area, as well as to confirm the validity of the established tectonic model.

Seismic line DEE1-364

This line is located to the north of Ras Budran area in the NE–SW direction. The step faults affecting the area and the down stepping to the west are obvious. The shear zone trending NE–SW is clearly demonstrated in the Ras Budran area (east of the section), in addition to the main bounding fault, which is crossing EE85-7C well and getting the basement against the Miocene and Pre-Miocene sections. Three wells are located on this line, these are EE85-7C, RBA3A and RB-A6. The big graben, which separated Abu Zenima basin from Ras Budran area to the west, can be distinguished. as shown in (Fig.17).

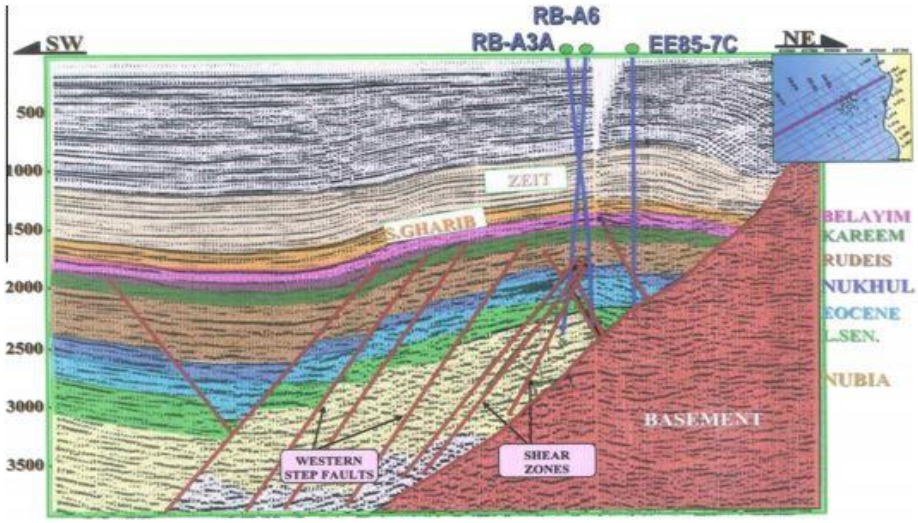

Fig.17 Interpreted 2D seismic line (DEE1-364) in northern part of Ras Budran field showing shear zones and western step faults.

Seismic line DEE1-285

This line extends in the NW direction (Fig. 18) from Abu Zenima area to Ras Budran area. It shows the in-between graben, that separates Abu Zenima area from Ras Budran area. Going to Ras Budran area, the section is cutting by a major shear zone. The main E–W faults down stepping to the south and bounding Ras Budran blocks are clear. In the southeastern part (toward Abu Zenima area), the Miocene section attains its maximum thickness at AZ13-1 well.

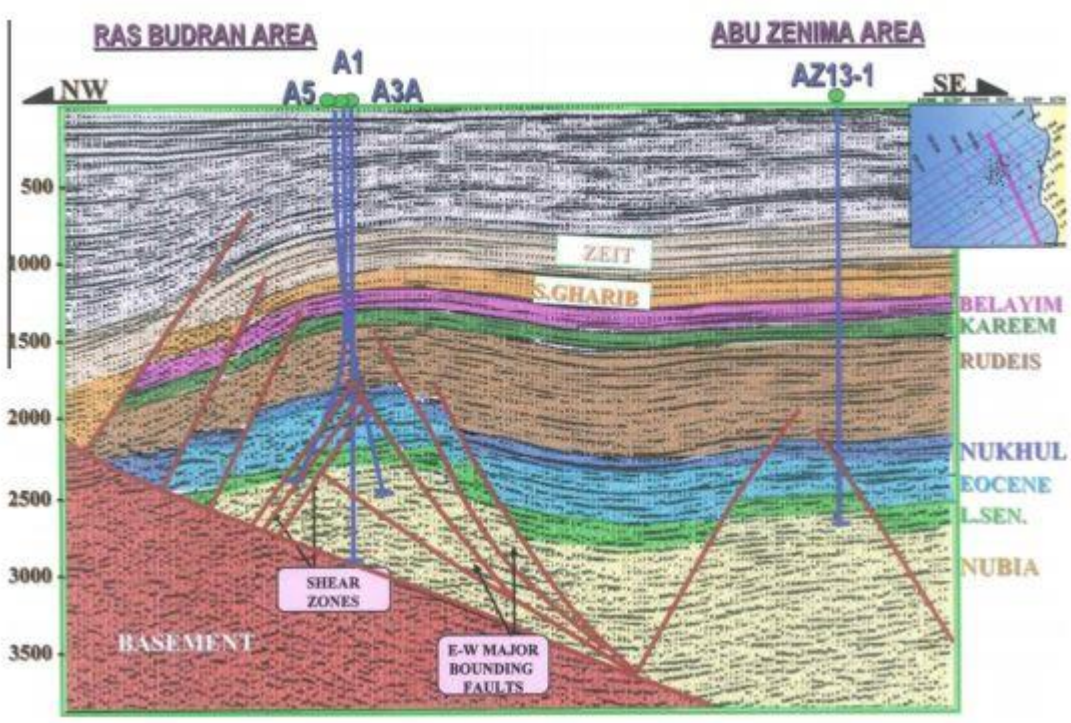

Fig.18 Seismic line (DEE1-285) extends in NW–SE direction between Abu Zenima and Ras Budran, showing graben between them

Seismic line ABZ-88-18

It extends from Abu Rudeis area to Ras Budran area (Fig. 19) in the N–S direction. The wells: ARM-3, ARM-2, AZSW-1 and Baba-M-l are projected on the line. The central horst, which is running in Clysmic trend and extends from Abu Rudeis area to Abu Zenima area, can be illustrated. In addition, the listric fault, which cuts at

shallow Miocene levels, is obvious. The graben of Abu Zenima basin, which occurred between Abu Rudeis area and Ras Budran area to the north, is demonstrated.

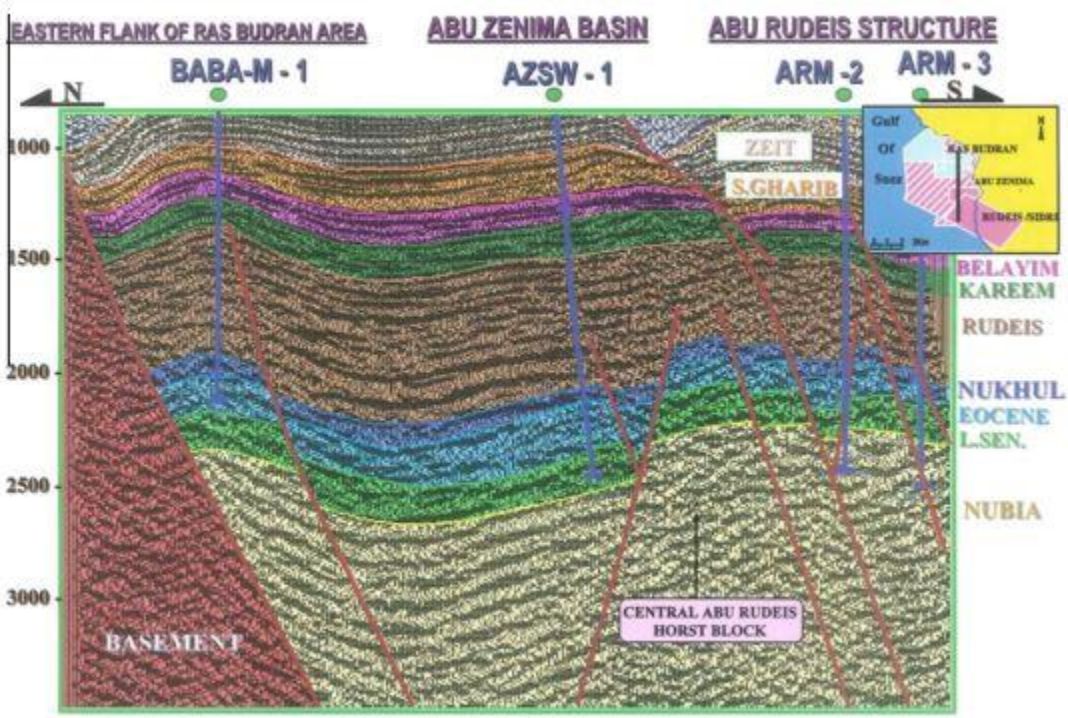

Fig.19 Regional 2D seismic line (ABZ88-18) extends through Ras Budran–Abu Rudeis area.

Interpretation of 3D seismic data

Recently on 1997, a 3D survey (OBC-Deep marine) was acquired to cover the eastern part of Ras Budran area and to extend the seismic data over the on-shore area. The relatively bad quality of the 3D seismic data, especially in the Pre Miocene horizons, does not allow the construction of reliable maps. As a result, the deepest mapped horizon was the base of the Belayim evaporites (top Kareem Formation). Six 3D seismic key sections are selected to illustrate the different structural elements of the reliable horizon (top Kareem Formation) as shown in (Fig.20).

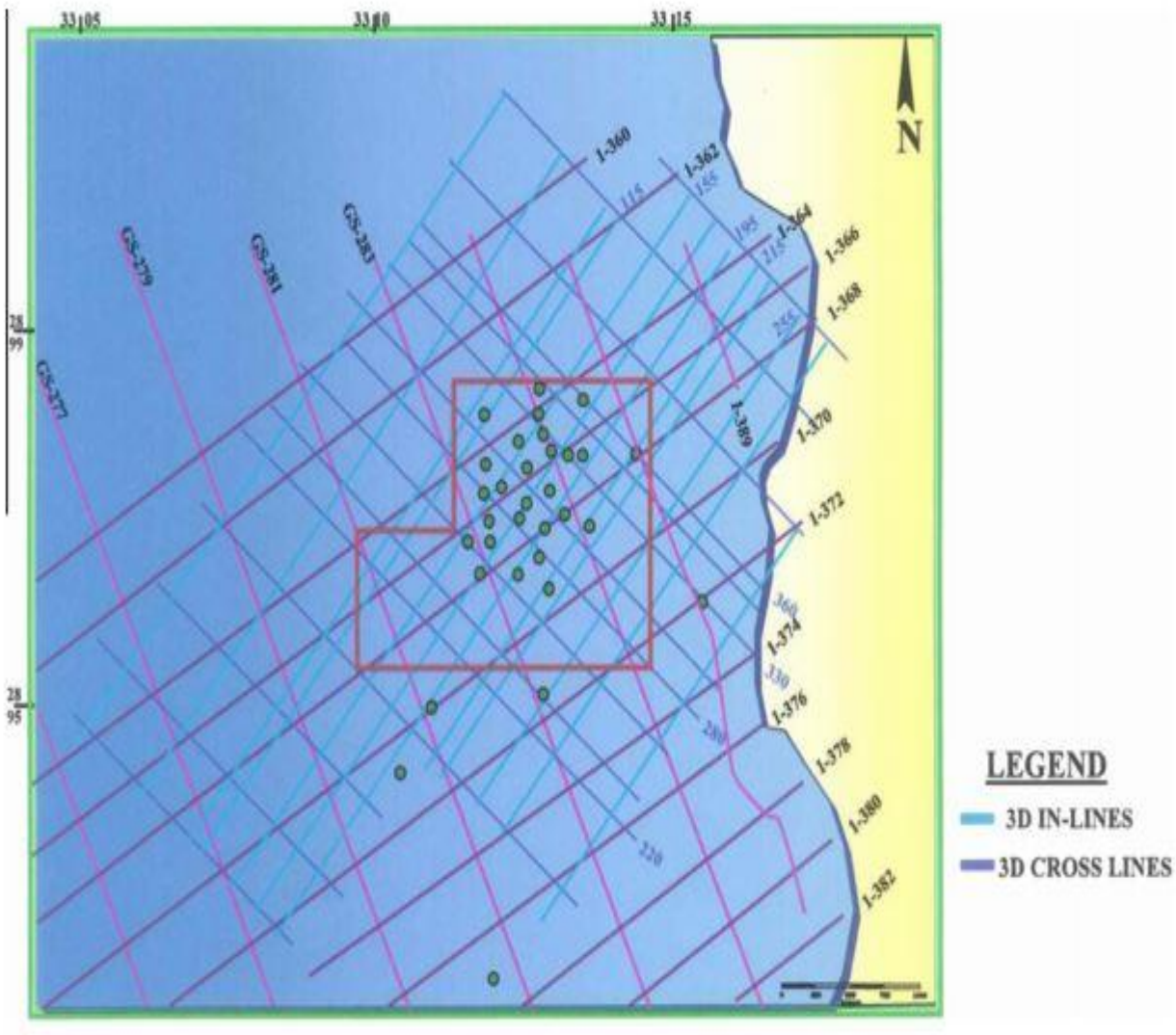

Fig.20 3D seismic base map of Ras Budran field showing the locations of interpreted key seismic lines.

Seismic in-line 215

This line bounds Ras Budran area from the southeast , in parallel to the two previous lines. The wells: Baba-M-1, RB-A10, EE85-2 to the east, added to RB-C3 in the southern part of Ras Budran field are located on this section. The drag of the Miocene strata along the eastern main bounding fault is clear. The basement rocks juxtaposed the Miocene section by this fault , as shown in (Fig.21).

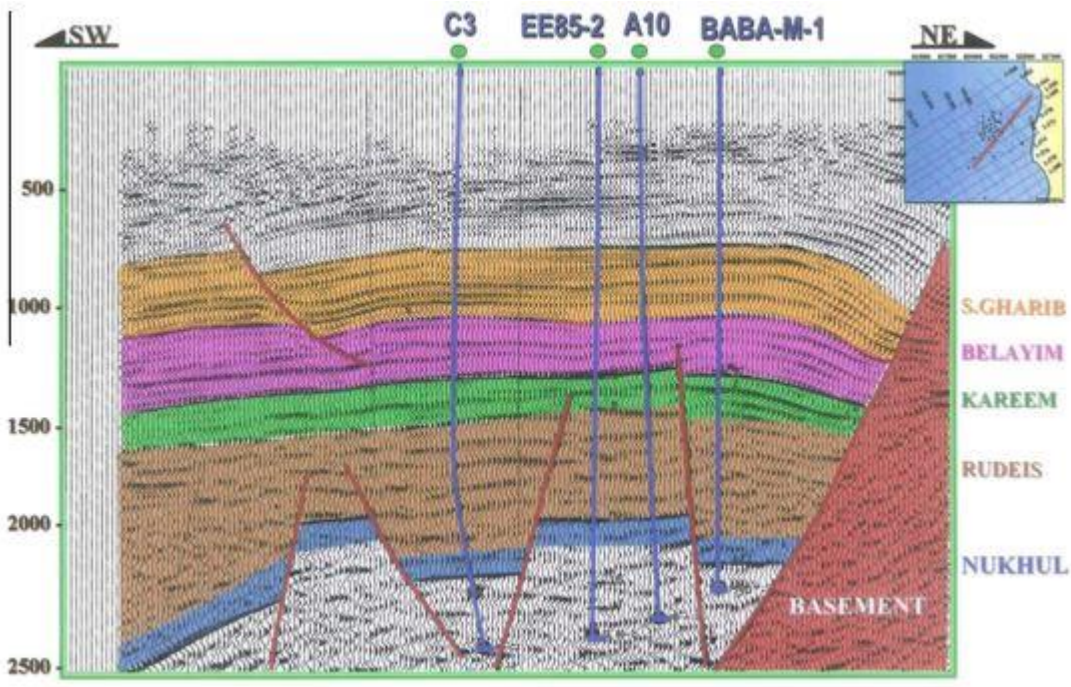

Fig.21 Interpreted 3D seismic in-line 215 showing the drag of Miocene strata along the main bounding fault and homogeneous

Seismic in-line 195

It is parallel to the previous one (Fig. 22) and extends from the southeastern part of Ras Budran field to Abu Zenima area. The well RB-A10 to the east, added to RB B3, RB-B7 and EE85-6A wells are located on the section. The eastern down faulted block, in addition to the horst of the main Ras Budran field can be distinguished. The graben separated Ras Budran area from Abu Zenima area is clear. The Kareem

Formation in the central part is of regular dip, which exceeds toward the two flanks of the section in reversal directions.

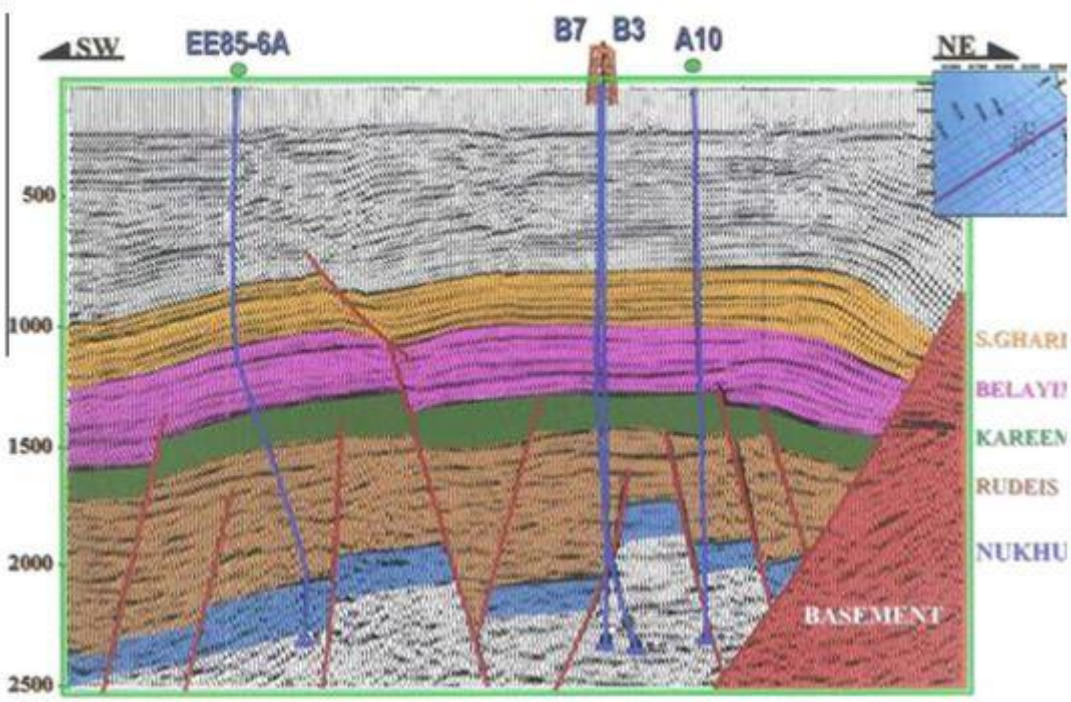

Fig.22 Interpreted 3D seismic in-line 195 which covers the south eastern portion of Ras Budran field.

Seismic cross line 360

It is in the NW direction of the area and bounded the eastern part of Ras Budran field (Fig. 23). The well Baba-M-1 is located on this section. The Miocene strata in the southern part of the section are flat and very steep in the northern part. The faults down stepping to the north are clear in the northern part of the section.

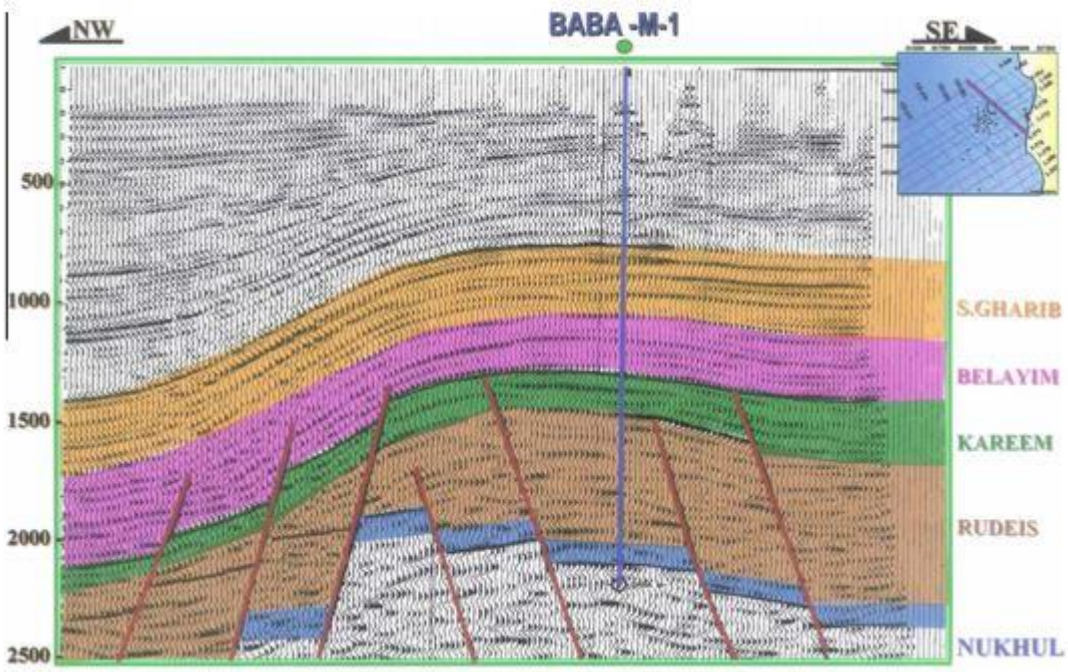

Fig.23 Interpreted 3D seismic cross-line 360 in NW–SE direction showing the dip change of Miocene strata.

Structural configuration of study area

the structural configuration of the studied area is implicated by two structural features superimposing each other, the Miocene (Rift sequence) where the faults trend in a NW direction (Clysmic) and the Pre-Miocene (Pre-Rift sequence) where the faults trend in a NNE to N–S (oblique) direction.

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